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GODDARD RESEARCH AND ENGINEERING MANAGEMENT EXERCISE (GREMEX)

Edited by Richard F. Baker

Goddard Space Flight Center
Greenbelt, Md. 20771

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16. Abstract

Goddard Research and Engineering Management Exercise (GREMEX) is a computer assisted management simulation exercise. Participants (individuals or teams) learn to become more effective managers by manipulating factors of time, cost, and technical performance in a research and development project environment. Participants must deal with human relations factors and random accidents of nature as well.

GREMEX may be purchased at a nominal cost for non-NASA use. Little or no modification is required for many career development requirements.

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FOREWORD

In early 1962 when aerospace research and development projects were approaching peak effort and attention was focused on the technical state of the art and on prestige schedules, the question of effective management of the vast human and financial resources was overshadowed. Recognition of the significant facet of technical research and development, and a conviction that "something can be done about it" led to what is in itself a research and development effort of considerable magnitude. The "something" was the concept, design, development, and test of a sophisticated management simulation game, in which simulation techniques and the versatility of computers are employed to provide experience in R&D project management.

This R&D activity resulted in the Goddard Research and Engineering Management Exercise (GREMEX). The simulation exercise was conceived by Dr. Michael J. Vaccaro, Goddard's Director for Administration and Management, and developed under his direction. The mathematical model was formulated under contract by Management Technology, Inc. The computer program was contributed by the IBM Data Processing and Federal Systems Divisions. The feasibility demonstration was planned and successfully executed by Mr. Milton F. Denault, Head of Goddard's Management Information Systems Branch.

Effective October 1968, the responsibility for further development and routine operations was transferred from the Management Information Systems Branch to Richard F. Baker, GREMEX Exercise Director, Manpower Utilization Division. The enthusiastic responses of Government, Industry and University participants indicate that GREMEX has great potential as a means of teaching R&D executives about the inherent problems of project management, their analysis and evaluation, and means of dealing with them. Thus, GREMEX offers a unique opportunity for transmitting management technology by way of a simulated project management environment.

John F. Clark

John F. Clark
Director

". . . I can think of no other area of administration where we need to be more innovative than in the organization and management of large technologically based enterprise --- both public and private."

Detroit
April '62

James E. Webb
Administrator
National Aeronautics and
Space Administration

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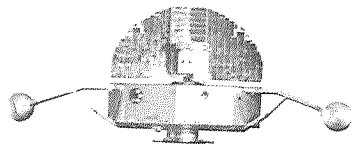
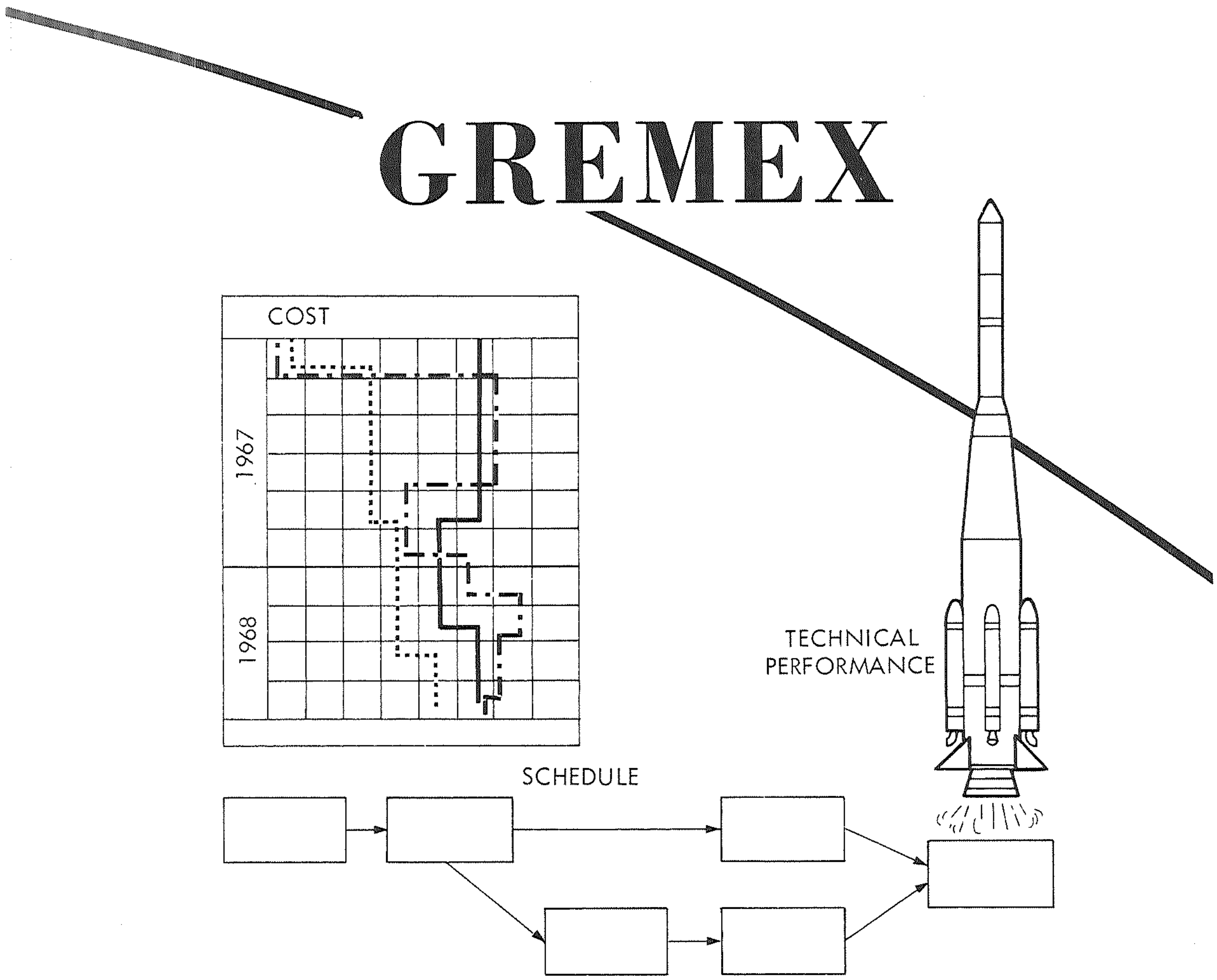


GREMEX



GODDARD RESEARCH AND ENGINEERING MANAGEMENT EXERCISE

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Edited by
Richard F. Baker
Goddard Space Flight Center

GREMEX-A NEW MANAGEMENT TRAINING CONCEPT

Need Becomes Challenge

The explosive growth of science and technology created a seemingly overwhelming paradox: the effective management of vast manpower and dollar budgets allocated to programs whose goals were well defined, but whose achievement required a course of action evolved from a myriad of alternatives.

This problem was particularly acute in connection with the nation's space program. There, scientific needs and technological development must be blended and matched against the harsh realities of available manpower, funds, and time schedules. One of the major consequences of the rapid growth of the space program was the shortage of engineers and scientists who had demonstrated ability in technical management. Also, the very newness of these efforts has often forced this program to be more concerned with technological advance than with technical administration.

As new programs were conceived, this deficiency became even more critical. Frequently, the approach used by both industry and government has been to advance engineers and scientists to technical management positions almost entirely on the basis of their technical accomplishments, with little regard to their education, experience, ability, or necessary desire for management functions.

In planning and managing today's complex scientific expeditions into outer space, the project manager must chart a course from innumerable alternatives, often without precedent or previous experience.

GREMEX-An Aid to Management

In an effort to meet the shortcomings just discussed, management simulation techniques are being employed to offer training in management problems. GREMEX (the Goddard Research and

Engineering Management Exercise) was developed to provide experience in R&D project decision making from a management rather than a technological perspective.

Techniques of simulation are well known to engineers and scientists in the analysis of complex physical phenomena. The advent of the computer provided an important tool. Simulation techniques are now used to predict inventory or market trends — even election results. Using computers, the military has developed war gaming into a highly sophisticated art.

Whatever their application, these techniques are designed to simulate a changing situation through the passage of time, through actions taken to modify the status-quo, and through the ever present variables which are beyond control.

Hypothetical Project

A hypothetical project, The S-101 Orbiting Optical Observatory, is the setting for the GREMEX exercise. The game begins when a Project Plan (PP) is given to the participant for study. This represents a situation in which the technical objectives have already been established; development and testing activities have been defined and their costs estimated. An optimum time to complete project development also has been established. In addition, the probability of success of the testing program, i.e., project reliability, has been estimated.

Built into the model are *inherent success probabilities* in regard to reliability, cost, and time estimates of each of the development and test activities. As the exercise progresses, these are used to determine the actual time and cost consumed, and whether technical performance objectives were realized.

The player (participant) in the exercise, who assumes the role of the project manager, influences performance, cost, and time estimates, etc., by decisions he is given the opportunity to make — or not, if he so chooses. For example, if the participant will determine the type of contract, select the contractor, and award the contract quickly with proper judgments applied, he will better his chances of achieving time, cost, and performance objectives.

As in real life, the plan is only a plan — a best estimate of all the required activities, probable success, and required resources. Also, as in real life, changes will occur, special technical problems will arise, and planning will be found to have omissions or to have been either optimistic or overly-competitive in its precontractual estimates. These problems, arising with and without warning, require responsive action.

For instance, when the success probability for cost and time parameters falls below 0.50, the actual cost and elapsed time will be increased. Likewise, when the success probability of a test falls below a specified reliability level, and bad luck is encountered, a test will fail. These failures will then require additional work which costs time and money.

The manager will be informed through both formal and informal reports, which he must first request and then use. He may, for example, require great reporting depth and detail down the

hardware hierarchy, even to individual subsystems and activities, if he so desires; or he may request specific reports concerning particular aspects of the program. In this way, the manager can choose his own patterns of personal operation and use differing degrees of formal or informal reporting, as he wishes.

As the exercise progresses, the manager will be called upon to analyze his development concept, decide on different system approaches, and consider and develop his reliability approach, and approve contractor changes. These proposed contract changes, as well as a number of other special problems of technical and administrative nature, arise periodically throughout the exercise. They are known as *perturbations*.

The manager must also look ahead and obtain the funds needed for his project. He must go through the budget cycle if he is to have the money when he needs it — or he can re-program within his allocation.

The game is flexible enough to accommodate most management techniques, but does not provide more than typical printed output reports; any graphics have to be originated and maintained by the players.

To prevent only classic solutions, certain factors in the mathematical model are compared against a purely random number. This comparison may generate a change in the project status which could not be anticipated, and so may require a change in the participant's approach; or at least, it will require an analysis of his position.

The player thus has opportunities to test his old methods and, if he wishes, to try some new approaches. This he can do without being concerned about the potential rewards or penalties that may weigh his decisions in real life. He will, undoubtedly, discover areas of weakness that are open to training, indoctrination, and improvement in general.

Exercises are conducted in a series of periods, or plays, one month apart in simulated project time. As many as 12 individuals can participate at one time — unless team play is used. (Team play not only allows a team leader to evaluate his team members, but can be useful in evaluating the personal characteristics and team interactions that could assist or impede project progress. Goddard conducts exercises of 12 to 16 players using the team approach. Teams normally consist of 3 to 4 players each, with one referee-instructor assigned to each team.) The simulation is non-competitive and the actions of one participant (or team) do not affect the others.

The Exercise Starts

The exercise director and his staff present an orientation lecture about one week prior to exercise play. During the lecture, participants learn about the exercise and what will be expected of them. They also receive their player manuals which include four authentically simulated documents essential to a project manager in real life as follows:

1. The Project Plan (PP)

2. Source Evaluation Board Reports (Contractor Evaluations developed by an official NASA review board)

   a. Technical Advisory Committee Evaluation Report
   b. Business Advisory Committee Evaluation Report

3. Detailed Schedules and PERT Charts

4. Work Breakdown Structure

The PP is an extensive description of the simulated project containing the following:

1. Identification
2. Project objectives
3. Technical plan
4. Major support interfaces
5. Procurement
6. Schedules
7. Resources
8. Management plan

The overall objective of the Orbiting Optical Observatory Project is to launch and operate orbital spacecraft to conduct experiments in solar physics above the earth's atmosphere and in the magnetic field. Included are a number of potential experiments from universities and research laboratories. Their purpose or mission include the following:

1. Make optical observations of the sun
2. Make magnetic field measurements
3. Determine the direction and intensity of ultraviolet light, gamma radiation, and the polarized component of zodiacal light.

Figures A-1 through A-6 in the Appendix, which are from the PP, describe the salient features of this simulated project.

Armed with these data and other material in the Player Manual, the project manager is ready to approach the first decision period of the exercise. He is required to recommend contractual action for the spacecraft and the experiments he decides will be available for the project's launch.

The Technical Committee Report contains all the information on the technical qualifications of five offerors selected from real life. The Business Committee Report contains the findings on the management capability, cost effectiveness, and cost of doing business with the same offerors.

The Player Manual contains the necessary instructions for preparing computer input data and a description of the game, its philosophy, available reports and basic approaches that can be used to manage; i.e., SARP*, PERT**, Cost Reports, etc.

At the beginning of play, the participant selects a spacecraft contractor, experiments, types of contracts, reporting requirements, and dates for start of work. These actions are converted to computer data by the referee - instructor (See Figure 1).

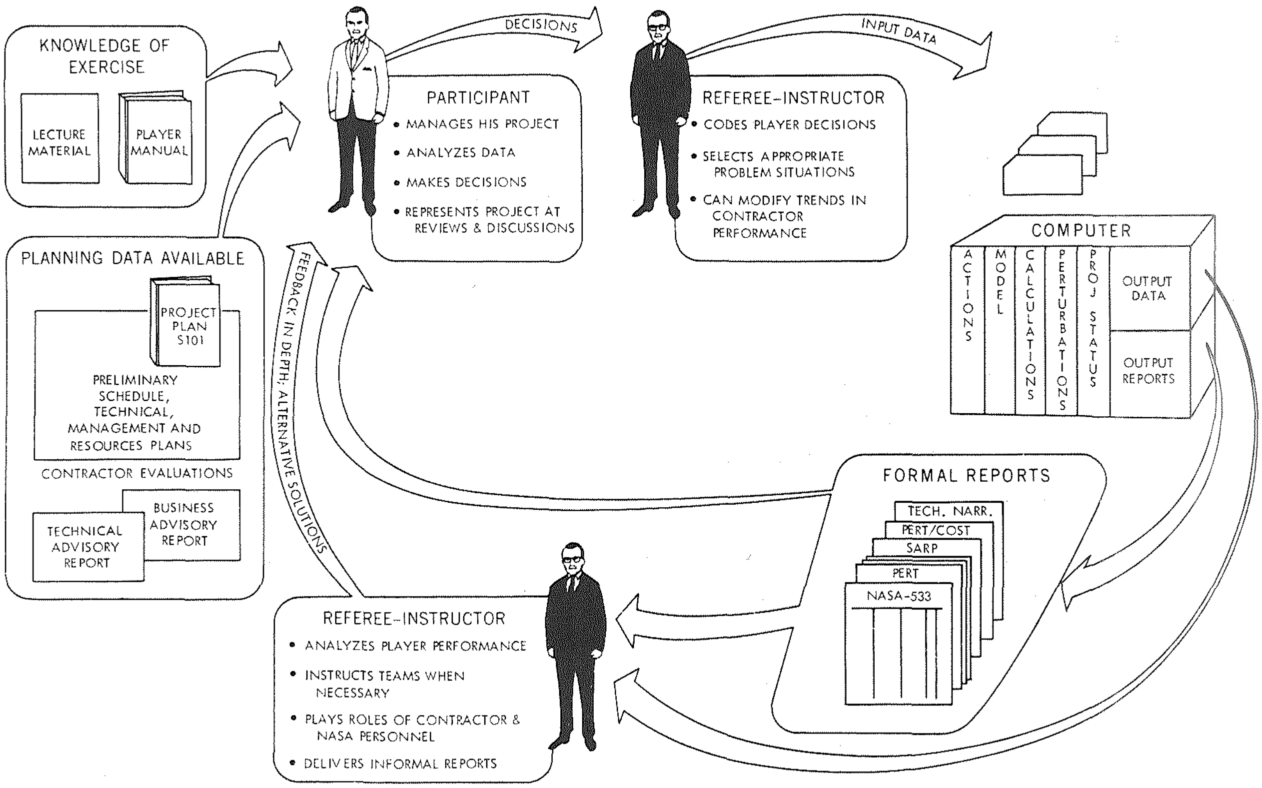


Figure 1.

The computer uses this input data to establish initial conditions in the project network, compute the necessary probabilities, advance the time frame one month, and generate the reports requested by the player as well as information for the referee. FORTRAN IV computer language is used for programming.

The player is confronted with the results of one month's progress reported in the manner and depth of his own choosing. Based upon this information, he can make new decisions, modify old ones, and prepare a required status report on the project as he sees it. At the end of the analysis period, the computer is fed data reflecting any new actions the player desires and the cycle is repeated.

*Schedule Analysis and Review Procedure Milestone Chart.
**Program Evaluation and Review Technique.

The referee-instructor acts as the buffer between player and computer, verifying the legality of the player actions on input and filtering the machine output to provide the player with the requested information and chance occurrences generated by the computer. The referee can alter trends in contractor performance and can influence the play environment through the triggering of perturbations. He receives both the true status (success probability) of the project and the player's status report for post-play analysis and discussion.

Inclusion of GREMEX in the management development process as a comprehensive exercise in project management, reinforces the learning achieved in the various specialty courses in Contracting, PERT, PERT/Companion Cost, and Problem Solving. It helps prepare the newly appointed project manager and his supporting staff for the complexities they must oversee, evaluate and direct — offering the obvious: better management of programs requiring large human and financial resources, and programs which test the nation's ability to conquer a vast unknown.

GREMEX IS AVAILABLE TO THE PUBLIC

The National Aeronautics and Space Administration (NASA) established several centers for the dissemination of space agency developments to the public. One such center is the Computer Software Management Information Center (COSMIC), The Computer Center, University of Georgia, Athens, Georgia 30601.

The GREMEX package may be purchased at COSMIC for less than $500. It comes in two parts: (1) the program for either the IBM 7090 series or the IBM 360 series computers (state your preference), and (2) the operating manuals including classroom materials. Since the program uses 256,000 bytes of core storage, the 360 series computer required must be a 360/50 or larger.

The GREMEX staff of Goddard's Manpower Utilization Division considers instructor training to be the most difficult phase of GREMEX implementation. Limited assistance in training referee-instructors is available from this staff.

Questions regarding the suitability of GREMEX to meet your particular training requirements and/or the availability of referee-instructor training may be addressed as follows:

GREMEX Exercise Director
Manpower Utilization Division
Code 220
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, October 22, 1970
039-06-01-02-51

Appendix A

The Simulation Technique

At the heart of the GREMEX program lies the model, complex and interacting. This model reproduces the philosophy and scope of research and development project management through mathematical analogs. When Management Technology, Inc., undertook the task of simulating through mathematics the relative effects of time, cost, and performance, it resorted to the theory and techniques of simulation well known to the scientific and engineering communities, and applied to the problems of decision making during World War II. How accurately the model represented the real life situation was proven in the successful first formal demonstration play.

The final step consisted of applying probability values to all project activities and player actions. The *probability* of time, cost, and performance success is the catalyst which generates game action in the mathematical formulae. The authenticity of probability values is essential to reproduction of a real-life environment. The expertise of seasoned personnel in all applicable disciplines throughout Goddard Space Flight Center was combined to define the mathematical values of these probabilities. Important features of this simulated project are shown in Figures A-1 through A-6 (taken from the Project Plan). Figures A-7 through A-9 depict excerpts from some of the articles written about GREMEX.

Model Structure Considerations

What will happen in the future is determined in part by:

1. What has happened in the past
2. The nature & quality of actions being taken
3. The probabilistic nature of the future conforming to present plans and estimates.

In terms of *effects* produced, participant actions may be classified as:

1. Certain — i.e., a known definite effect on the future time (schedule), cost and performance (TCP)
2. Uncertain — which may be expressed as a probability of a particular effect occurring.

Actions Having Certain Effects

Some actions having an absolute impact on time or cost (in some cases on performance) are:

1. Overtime approval — will have a known direct effect of reducing time and increasing cost

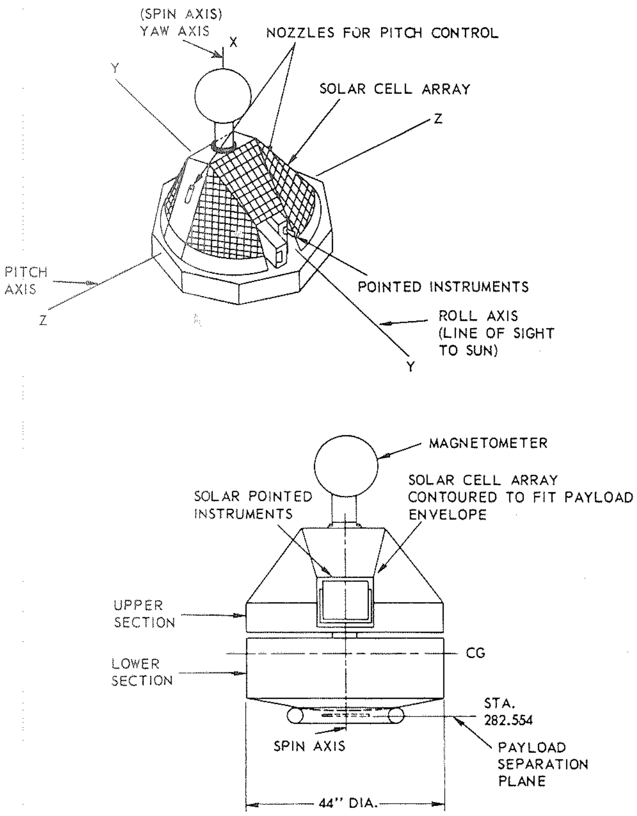


Figure A-1. Spacecraft Description.

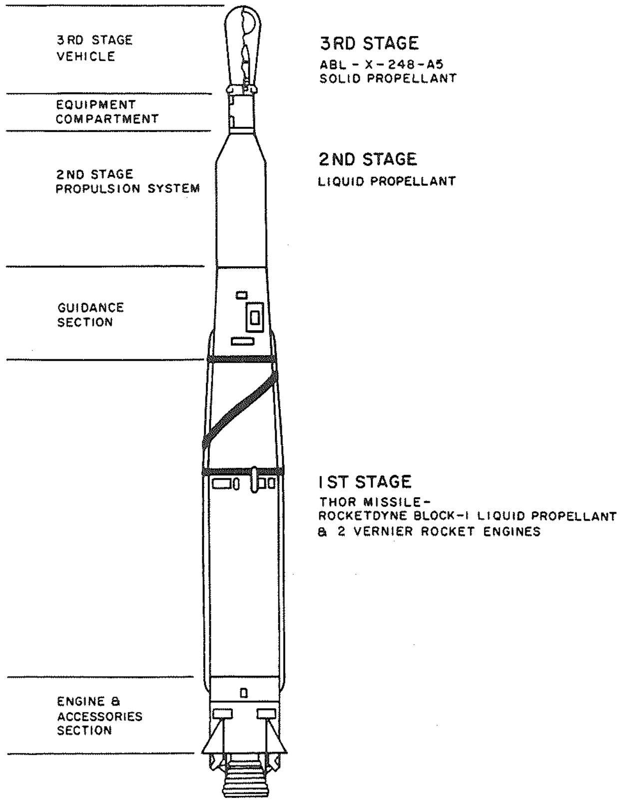


Figure A-2. Alpha Launch Vehicle.

2. Change in funding level — will have a known effect on dollars available
3. Contract Cancellation — will be a specific cost
4. Amount and detail of information requested — will increase cost in accordance with fixed increment.

Actions Having Uncertain Effects

1. At the outset there exists a predetermined probability of achieving time, cost and performance (TCP) targets.
2. Over 85 percent of the actions taken will effect the probability of realizing planned TCP targets.
3. Such actions taken at any instant affect the probability of one or more of the following:
   a. Achieving future schedules
   b. Incurring planned expenditures
   c. Achieving specified technical performance.

DATA SHEET
S-101 ORBITING OPTICAL OBSERVATORY

SPACECRAFT Weight: Size:	Approximately 500 pounds Lower section — 44 inches Overall height — 45 inches
Power System Supply: Regeneration:	16 watts total Telemetry, data system, and control system require 7 watts. Nine watts available for experiments which require a maximum of only 7.75 watts at any time. 4.52 square feet of solar cells, composed of 42 18-volt modules of 52 cells each. Power output of 30 watts.
Telemetry Subsystem Data storage: Data readout:	PCM/FM digital system Stored sequentially in digital form by tape recorder 5 minutes during each orbit
Command Subsystem	A GSFC digital system, providing 31 command functions for operation of spacecraft and lower section experiments and 19 command functions for operation of the upper section experiments.
TELEMETRY STATIONS	To be selected
LAUNCH PHASE Launch facility: Launch vehicle: Orbital plan: Orbital period: Launch plan:	Eastern Test Range Alpha Elliptical, 3000 ±200 apogee, 200 ± 50 perigee nautical miles. 270 ± 10 minutes Second quarter CY1969

Figure A-3. S-101 Data Sheet.

R&D ACCRUED COST AND OBLIGATION PLAN DATE:
(In Thousands of Dollars)

SUBMITTED BY:

CODE	PROGRAM/PROJECT/ SYSTEM CONTRACT	PLANNED			
		FY 1967	FY 1968	FY 1969	TOTAL ALL YEARS
	PHYSICS AND ASTRONOMY Orbiting Optical Observatory				
S-101	Spacecraft Prototype Flight	(An actual cost and obligation plan is distributed by fiscal year. In GREMEX time-phasing of this plan is performed by the participants.)			3,500
	Reliability				175
	Experiments				3,225
	Maine				310
	Stanford				430
	N.O.L.				260
	GSFC #2				200
	Mississippi				435
	GSFC #1				170
	Ohio				390
	South Carolina				320
	Texas				370
	U.S. Army R&D Lab.				340
	Total S/C & Experiments				6,900
	Alpha launch vehicle				4,667
	TOTAL NASA				11,567

Figure A-4. S-101 Funding Requirements.

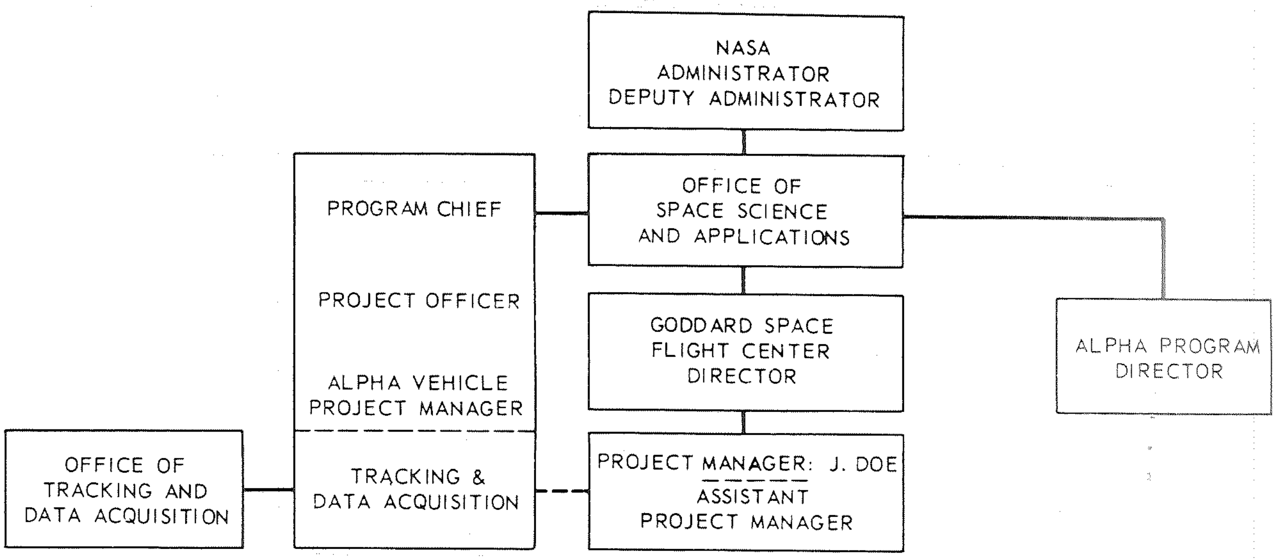


Figure A-5. Program Management Organization Chart.

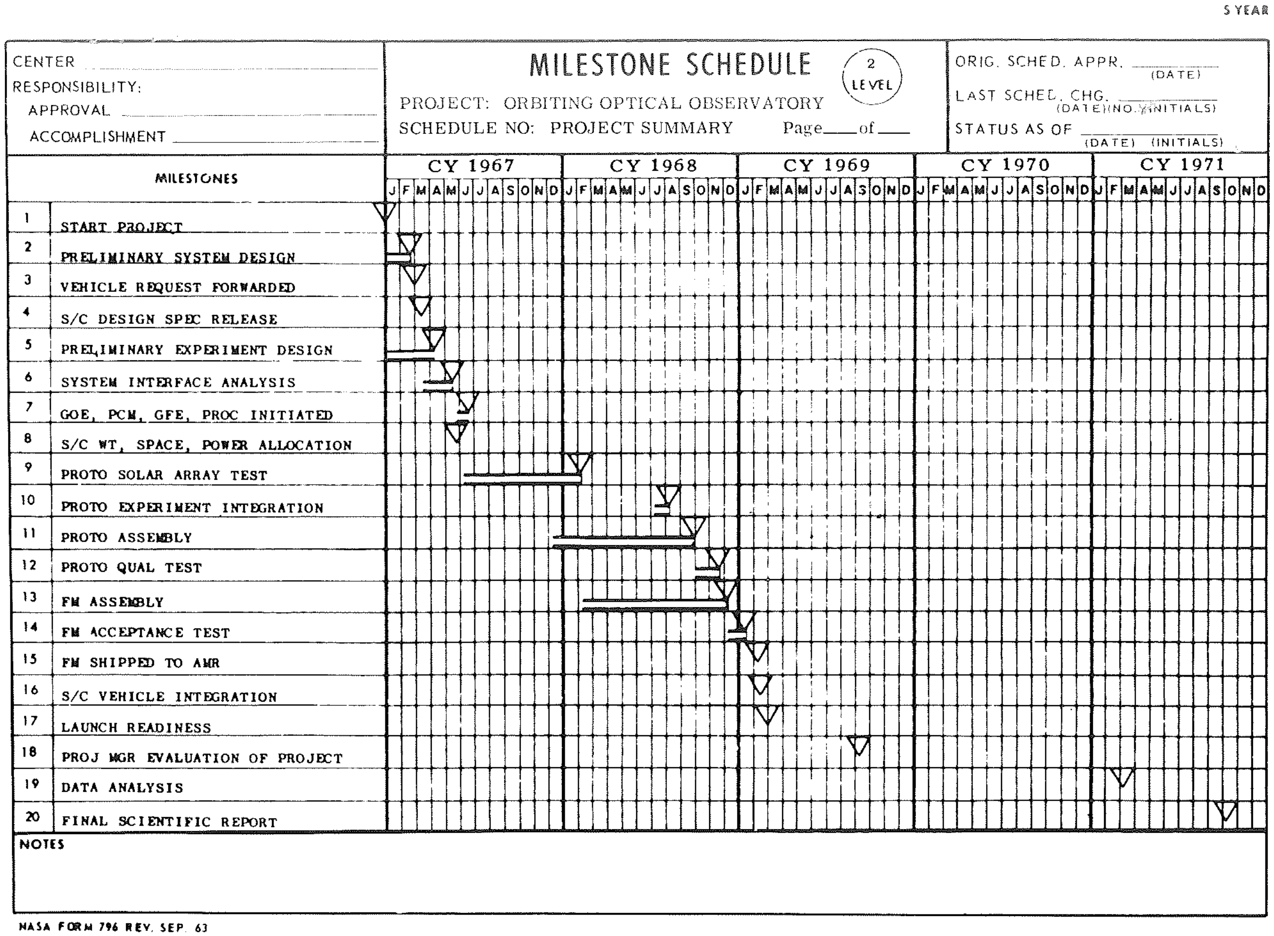


Figure A-6. Project Milestone Schedule — Summary.

As reported in.......

256 SCIENCE NEWS / Vol. 90 / 1 October 1966

It's 'Just a Game'

Technicians, engineers and professors played a game of managing a satellite project to study pitfalls and causes of failures in programs—By Jonathan Eberhart

➤ AFTER misguiding a $3.9 million satellite program over its budget by 50%, the guilty project manager simply shrugged and told himself that it was just a game—and it was.

Besides money. troubles, he was plagued for a week with such hypothetical problems as parts that would not fit together, sloppy technicians who short-circuited vital components, and memos from "on high" with warnings to drop everything and prepare next year's budget. Sometimes setbacks were encountered when it was found too late that some item had been magically left out of the blueprints.

Happily tearing their hair through all of these "perturbations" were a dozen players, including nine National Aeronautics and Space Administration engineers and technicians from space installations around the country, two business administration professors from the University of Southern California (including the head of the Master's Degree program), and from International Business Machines, the only real-life project manager in the group.

The game was called GREMEX Goddard Research Engineering ... game— ... full eight-... days and then took their studies home with them at night—but they made their mistakes. In selecting seven experiments for the satellite from among the 10 offered, for example, players who tried to save money by contracting for only the minimum seven invariably found that one or two of them became hopelessly delayed or simply did not work as planned.

Contracts were awarded late (resulting in a completed satellite with nothing to put in it), data were misinterpreted, and once, when everything was going smoothly, a memo announced that due to the failure of the previous satellite in the hypothetical series the entire program would have to be speeded up.

Too much speed was not a good thing, however. There were financial penalties for being behind schedule, of course, but also for finishing too early. The Government does not fancy paying the staff of a project that has finished early for sitting on its hands.

It is too early to know whether there will definitely be more such games, but there are so many people in the aerospace business in need of management training that it is not at all unlikely.

As reported in.......

Goddard News—September 19, 1966

Goddard's GREMEX Sharpens Executive Skills of R & D Supervisors

First Formal Demonstration Packed 13 Months' Decision-Making into 5 Days

Goddard has developed a new management tool which should prove invaluable in career development for key project management and other staff R & D supervisors who have extensive technical backgrounds but little or no prior business-management experience. The new computerized simulation program is called GREMEX (Goddard Research Engineering ... ercise).

... exercise employs and makes available all of the NASA management information and control systems used by the space agency, such as PERT and Companion Cost, NASA contractor financial report Form 533, and SARP scheduling.

GREMEX is considered to be the first such exercise specifically developed for complex space flight projects.

QUOTES

After participating in the GREMEX exercise, Professor David McConaughy, of the University of Southern California at Los Angeles, said: "The GREMEX exercise, in my opinion, will be extremely helpful to project managers at all levels of NASA. New as well as experienced project and program managers should benefit by such an exercise."

• • •

"I consider this one of the most informative and interesting training courses I have ever been exposed to. Although the participant is called a player and the input to the computer is called a play—it is not a game, however, the exercise is such that it will sustain a high level of interest through the entire training period."

Gordon J. Stoops
Apollo Spacecraft Program Office
MSC

"The dynamic simulation allows the participant to take actions and almost immediately realize the results. The fact that the results one obtains are based on actual results of similar real life situations gives them importance."

R. T. Duffy
Flights Test Division
Wallops

Figure A-7.

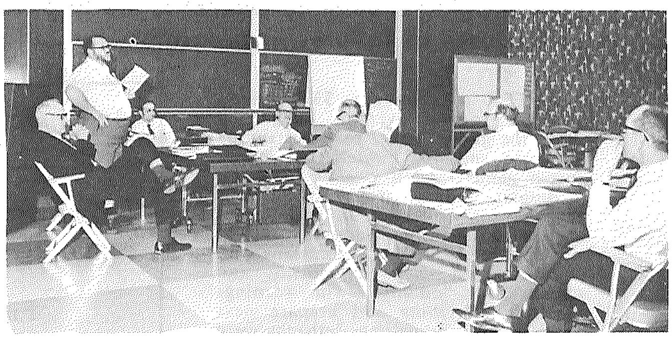
As reported in . . . . .

Goddard News - March 9, 1970

GREMEX:

Management Training for R&D Supervisors

A team of management specialists under the direction of Dr. Michael J. Vaccaro has developed a training exercise which draws heavily on GSFC project management experience. The exercise is called GREMEX: The Goddard Research and Engineering Management Exercise. The program is designed to give seasoned NASA personnel an in-depth exposure to decision making in a simulated project management environment. The simulation takes place in a seminar atmosphere through the use of a computer model, verbal role playing by GREMEX referee-instructors, and free exchanges between participants as they manage hypothetical projects. The GREMEX participants are divided into teams of four players with a referee-instructor assigned to each team. Each team directs its own project. Throughout the exercise, the players rotate management assignments within their teams, for example: project manager, project coordinator, financial analyst, schedule analyst and experiment coordinator.



GREMEX DIRECTOR'S STATUS REVIEW. Lloyd (Dusty) Rhodes (standing) presents his teams' status to "center management." The members of the team under review are: (from left) John Kimen, Q.A. Div.; Lloyd Rhodes, Inf. Proc. Division; Ronald Krellen, GREMEX Referee-Instructor; Luther Slifer, Spacecraft Technology Division; and Raymond Baker, Project Support Division. In the foreground (from the left) James Rice, Edward Shockey, and Charles Aitken are three of the reviewing officials that are role playing center management for this team's status review.

During a typical week of GREMEX play, student teams carry their "projects" through about 16 months of a 27 to 30 month project lifetime. Decision periods are followed by each team submitting their management decisions to the referee-instructor who prepares the computer input data on "IBM" cards. After processing, the referee-instructor distributes computer-generated contractor monthly reports. Students' moves include such basic spacecraft management tasks as drawing up technical plans which will meet mission objectives, choosing a spacecraft contractor, developing plans for funding up to 10 experiments, and organizing a management information system. Players must be prepared for unexpected occurances too, such as a tape recorder failure. Because the GREMEX computer model is based on the experience of actual spacecraft projects, good or bad management will produce results similar to developments in a real life project.

Richard F. Baker, Goddard's GREMEX Exercise Director, remarked, "GREMEX is a practitioner's exercise in decision making, not an academic course. Participants gain greater insight into many factors of decision making. Insight is developed by manipulating the factors in an effective learning environment in order to ascertain the relationships that exist between them. The environment (in the form of the computer model, the instructor, or fellow participants) responds to decisions by giving the decision-maker feedback as to the effectiveness of his actions. Most players find the exercise very stimulating and rewarding."

JOAN TOMASELLO, GREMEX Referee-Instructor, lectures to participants on the types of contracts available in GREMEX.

TEAM "PROJECT MANAGER" Anthony Caporale (left) directs questions to Richard Baker, GREMEX Referee-Instructor, (center) playing the role of Company C Representative during contract negotiations. Caporale, San Marco Project Manager; Charles Dunfee, Procurement Division; Richard Baker, GREMEX Exercise Director; William Forlifer, T&E Division, and Irvin Agree, Office of Instrumentation Ships.

Figure A-8.

Reprinted from. . .

January, 1970

educational technology®

Some Applications of Technology to Information Handling and Education at NASA-Goddard Space Flight Center

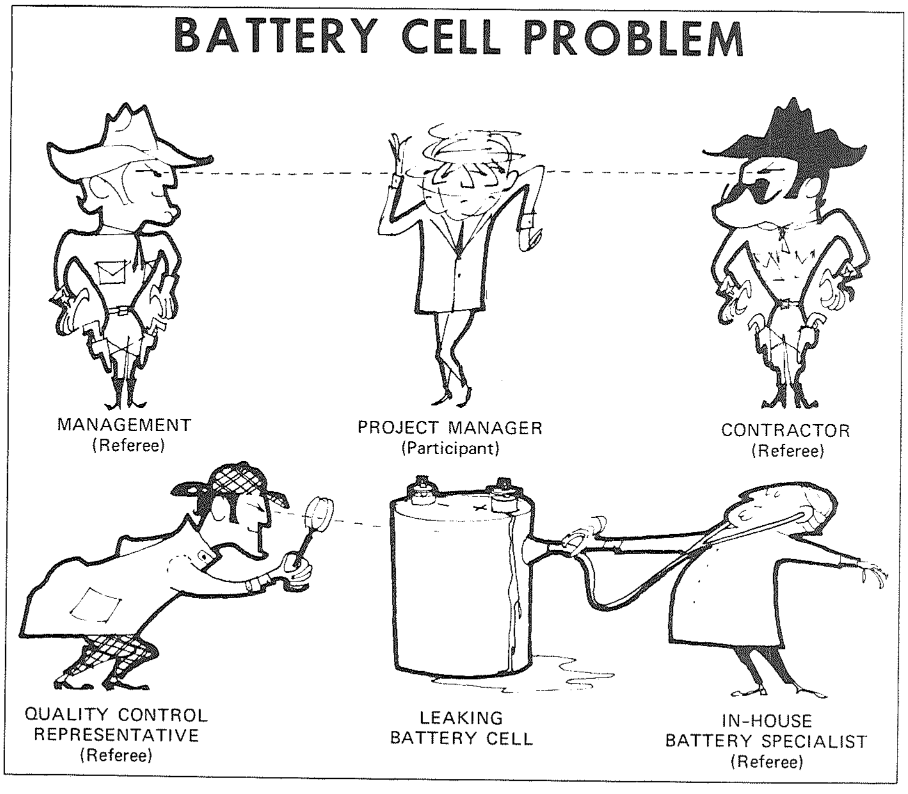


Figure 1. Examples of Interaction Between Referee and the "Project Manager."

Figure A-9

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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